INPC 2025

南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

The 29th International Nuclear Physics Conference

Observation of the third 2^+ state in ^{16}C via inelastic scattering reactions

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Outline

❑background：

- ❑ Magic numbers Z=6?
- ❑ History about Neutron excitation dominated 2^+_1 state of ^{16}C

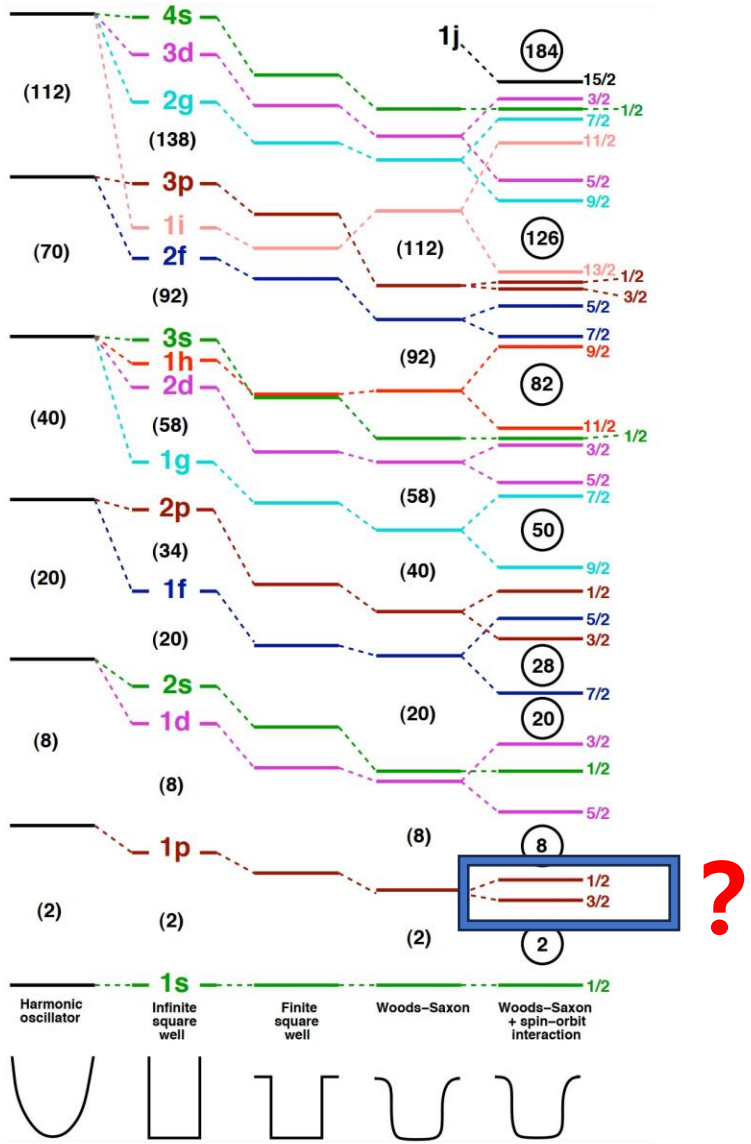
❑ Experiment:

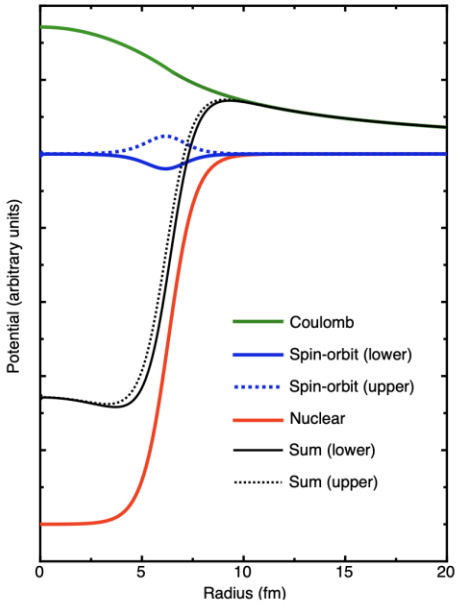
- ❑ Proton and deuteron elastic and inelastic scattering using the AT-TPC

❑ Result & Discussion

- ❑ Third 2^+ state of ^{16}C

Background: SO-splitting resulting in magic numbers





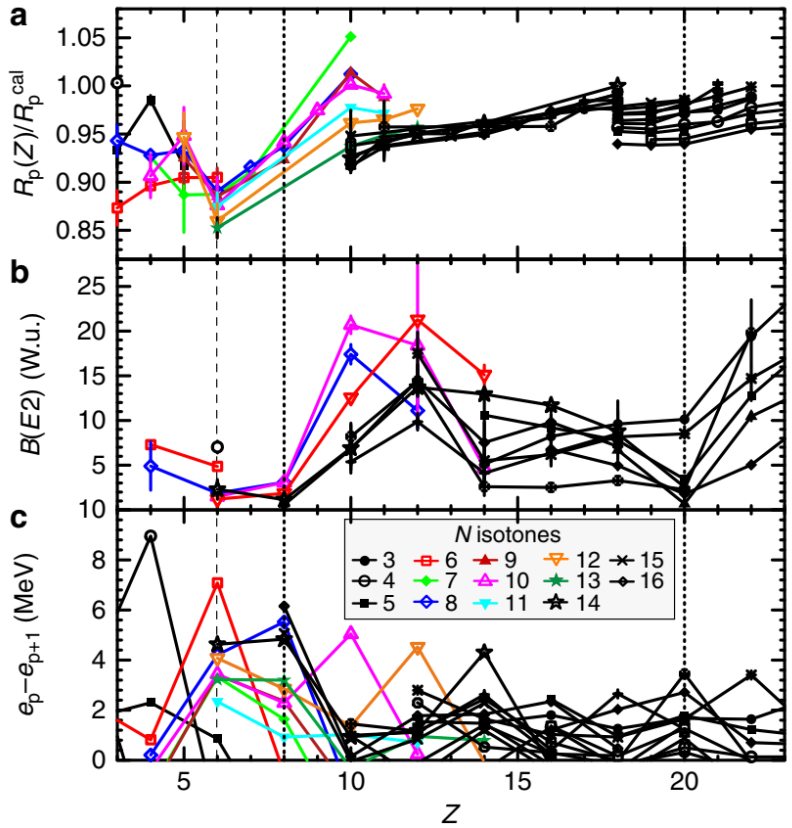
$$\ell \cdot s$$

Background: History about 2^+_1 state of ^{16}C

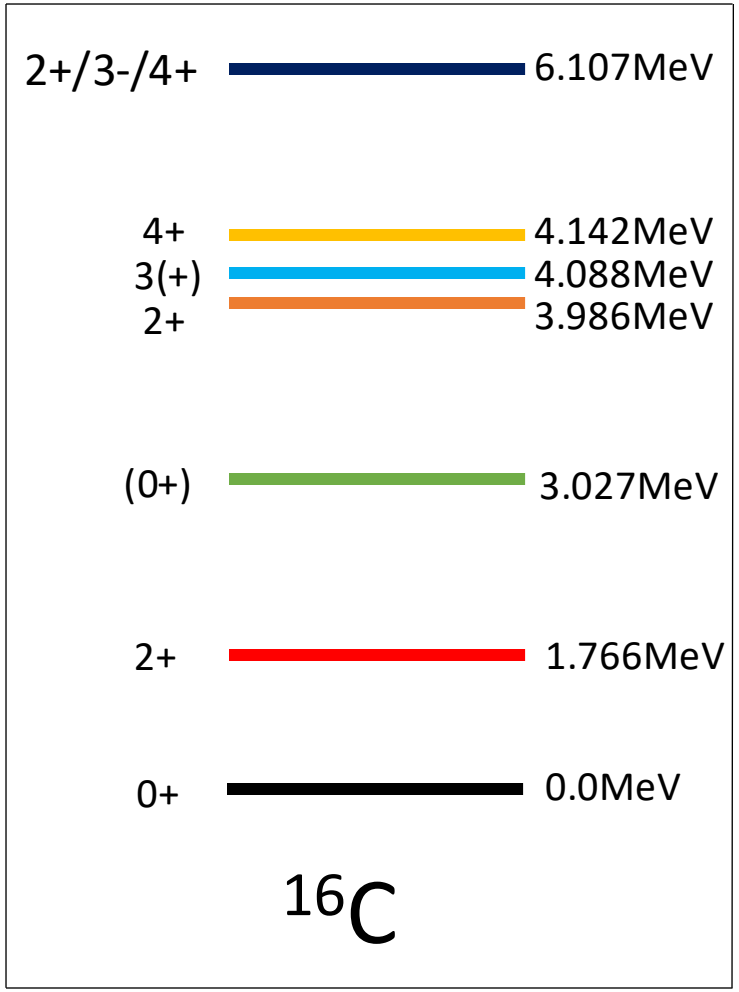
Systematic analysis of point-proton distribution radii, electromagnetic transition rates and atomic masses

➡ Z=6 is close to "magic" in ^{14}C !

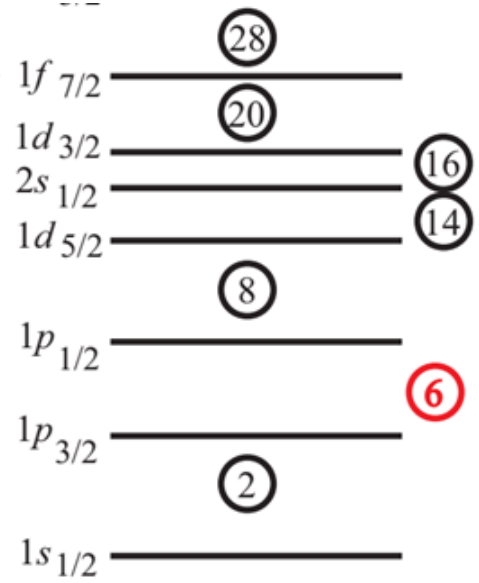
Just a local "magic" number?



D T Tran, H J Ong, G Hagen, *et al.* Nature Comm. 9 (2018) 1594



Shell model



Z=6 Test of the shell closure

N=10 2n in the sd-shell

Background: History about 2^+_1 state of ^{16}C

-- Deducing deformation length using two experiments approaches

Life time of the 2+ state

$$B\left(E2, J_i^+ \rightarrow 0^+\right) = e^2 \frac{M_p^2}{2J_i + 1}$$

$$\delta_p = \frac{4\pi}{3ZR} M_p$$

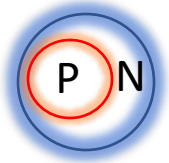
Inelastic scattering on deuterons/protons

$$(d\sigma/d\Omega)_{exp} = \delta_d^2 (d\sigma/d\Omega)_{DWBA}$$

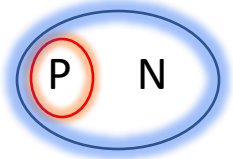
$$\frac{\delta_m^F}{\delta_p} = \frac{1 + \left(b_n^F/b_p^F\right)(M_n/M_p)}{1 + \left(b_n^F/b_p^F\right)(N/Z)}.$$

For deuterons, b_n/b_p=1
For protons, b_n/b_p=3

$\frac{M_N}{M_P} = \frac{N}{P}$ $\quad$ $\frac{M_N}{M_P} > \frac{N}{P}$



Proton-neutron strongly coupled



Proton-neutron not strongly coupled

J. Chen *et al.*,Phy. Rev. C 106, 064312 (2022)

A. M. Bernstein, V. R. Brown, and V. A. Madsen,Comments Nucl. Part. Phys. 11, 203 (1983).
A. M. Bernstein, V. R. Brown, and V. A. Madsen, Phys. Rev. Lett. 42, 425 (1979)

Background: History about 2^+_1 state of ^{16}C

-- Deducing deformation length using two experiments approaches

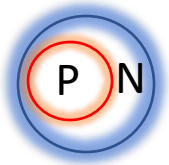
Inelastic scattering on deuterons

Inelastic scattering on protons

$$\frac{\delta_m^p}{\delta_m^d} = 0.44\frac{1+3M_n^{pd}/M_p^{pd}}{1+M_n^{pd}/M_p^{pd}}.$$

For deuterons, b_n/b_p=1
For protons, b_n/b_p=3

$\frac{M_N}{M_P} = \frac{N}{P}$ $\qquad$ $\frac{M_N}{M_P} > \frac{N}{P}$



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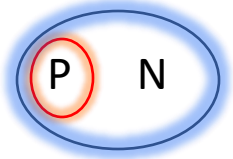

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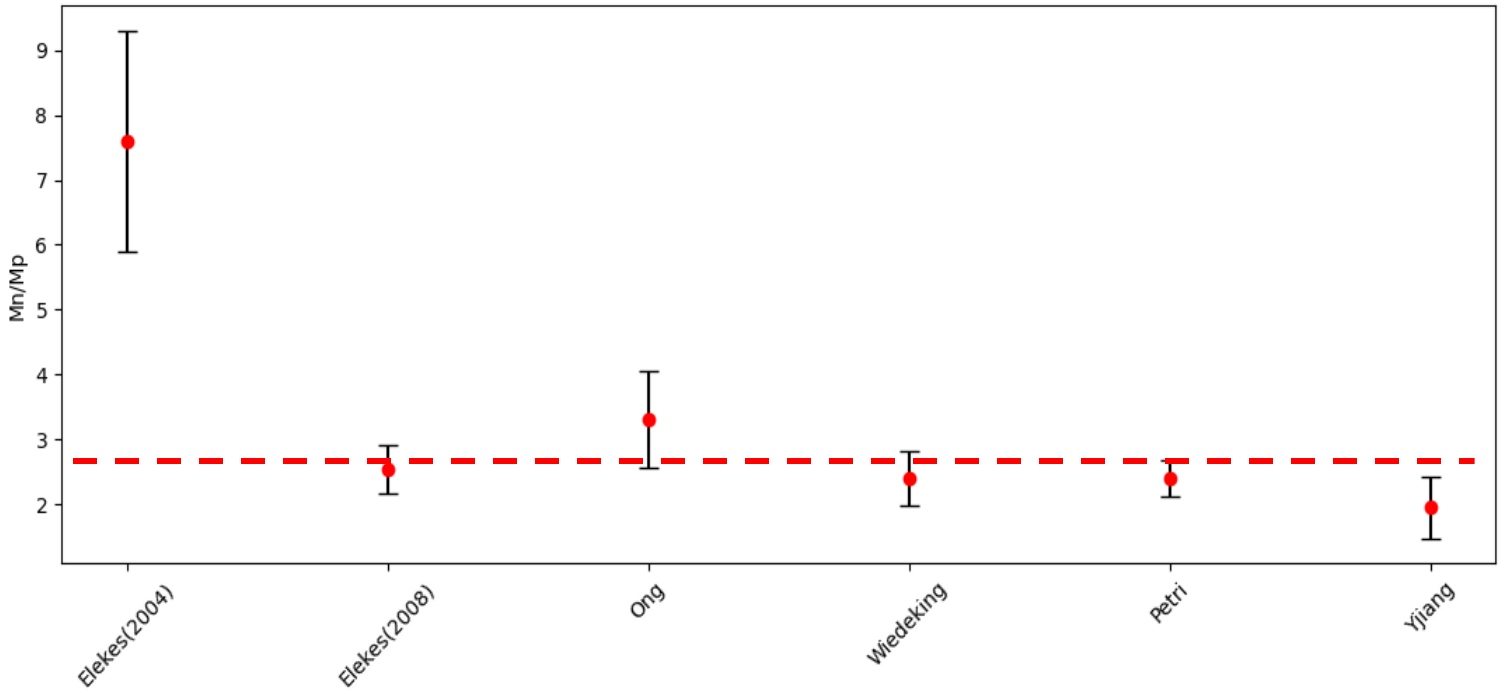
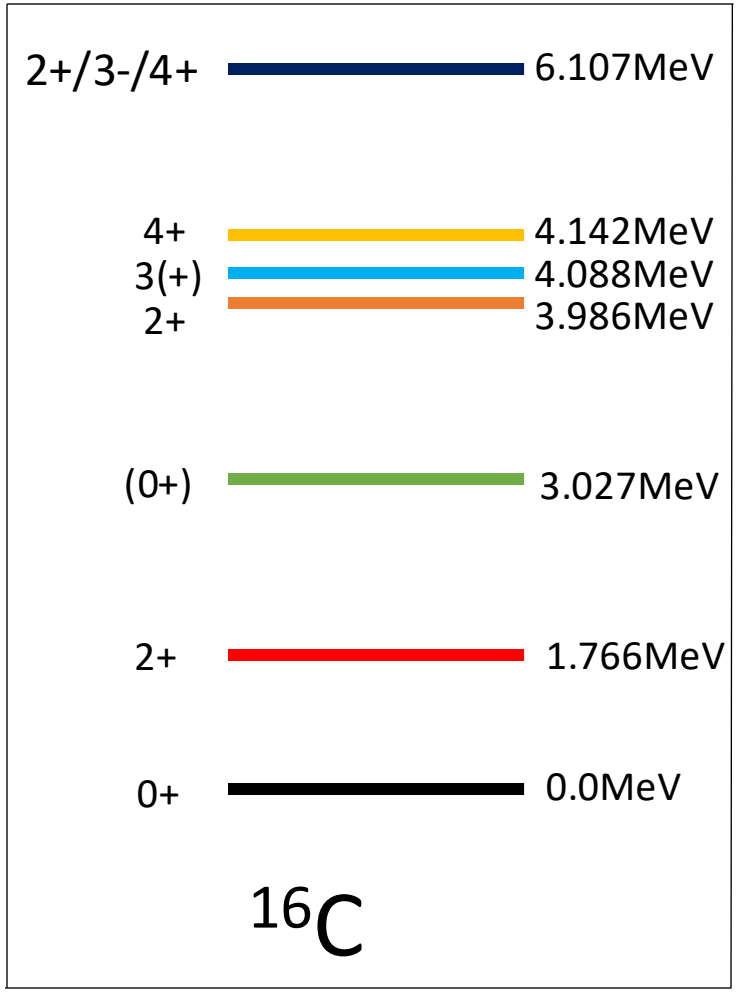
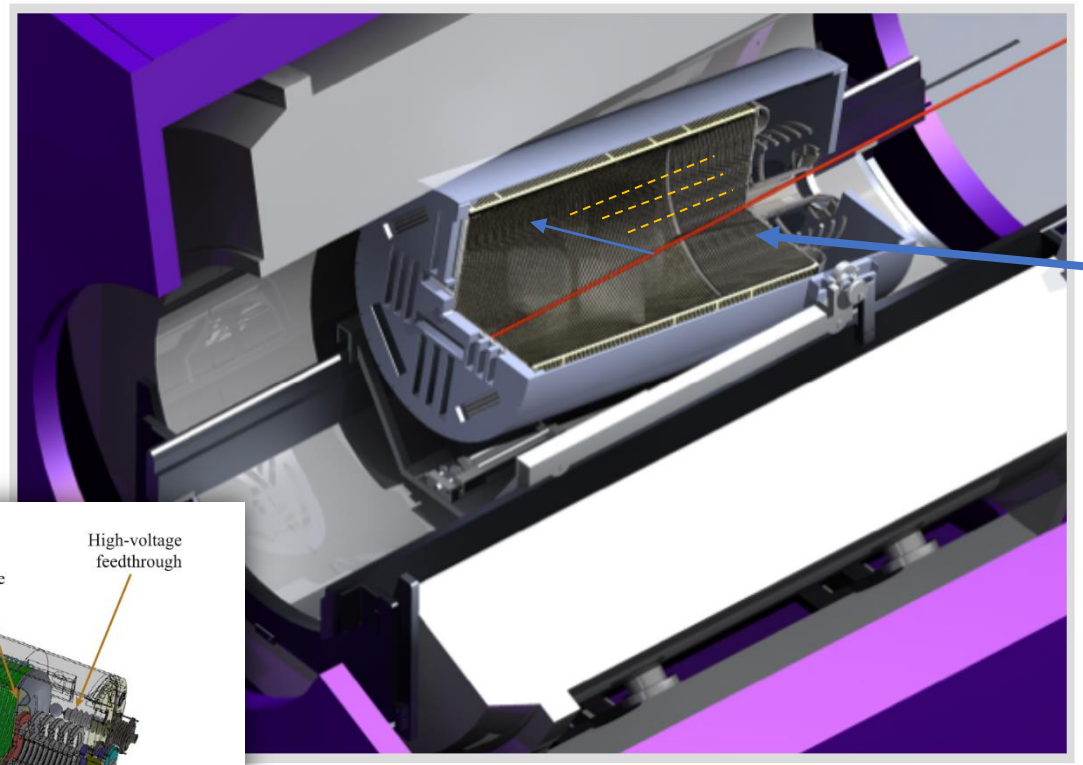


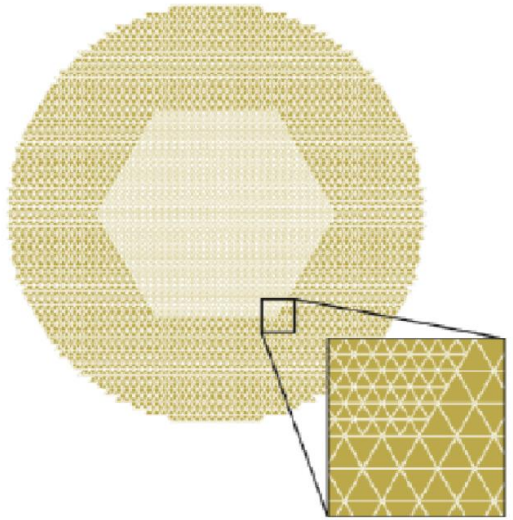


- The first 2+ state is dominated by neutron excitation
- M_n/M_p is still not conclusive
- M_n/M_p is close to the value of ^{18}O, where ^{16}O is a good core

Active target for direct reactions

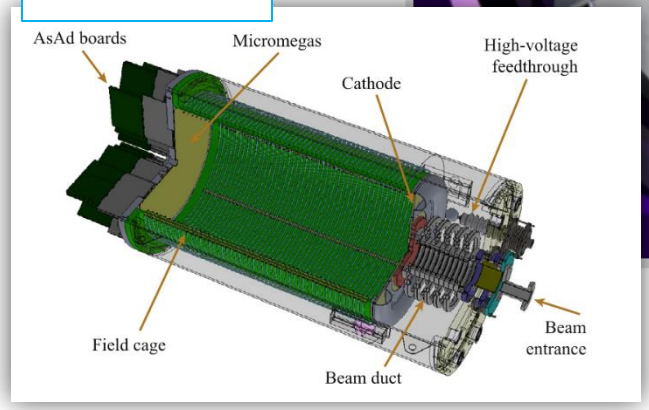
- AT-TPC: large-volume gas-filled detector ⟷ target isotopes as well as the tracking medium
- A large effective luminosity ⟷ beams as low as hundreds of pps
- Inelastic scattering reaction measurements with the AT-TPC coupling with HELIOS field





10240 triangle pads

AT-TPC



J. Bradt et al., Nucl. Instrum. and Methods in Phys. Res. A 875, 65 (2017)

Proton and deuteron inelastic scattering on ^{16}C

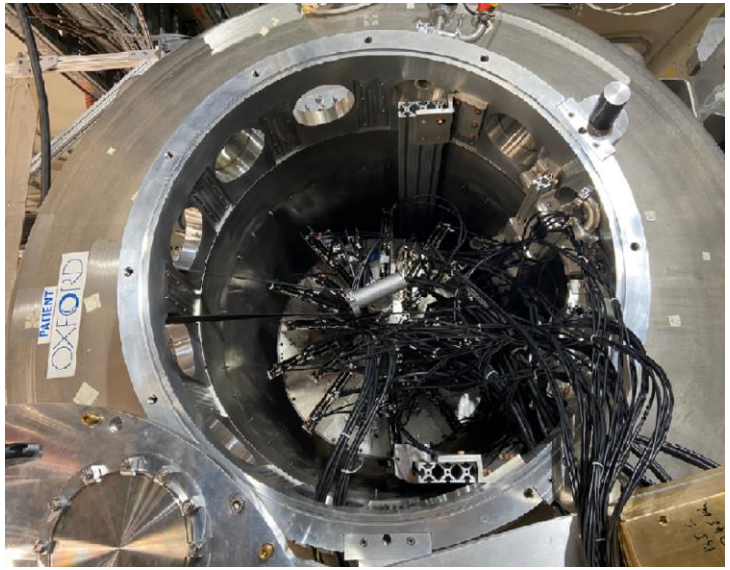
- $^{16}C(d,d')^{16}C$ and $^{16}C(p,p')^{16}C$ inelastic scattering measurement using the AT-TPC coupling with HELIOS @ ATLAS

Filled with D_2 and H_2: 300 Torr

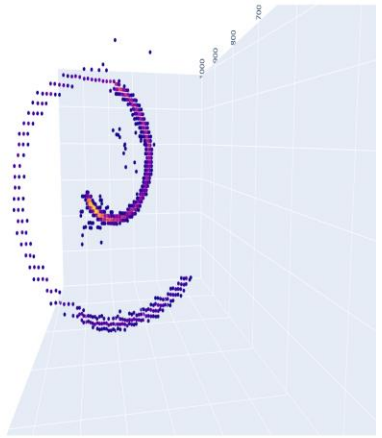
^{16}C beams @ 11.5 MeV/u

5000 pps

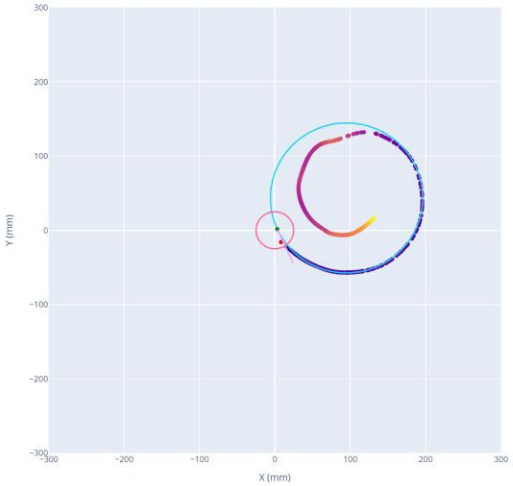
B=2.85 T

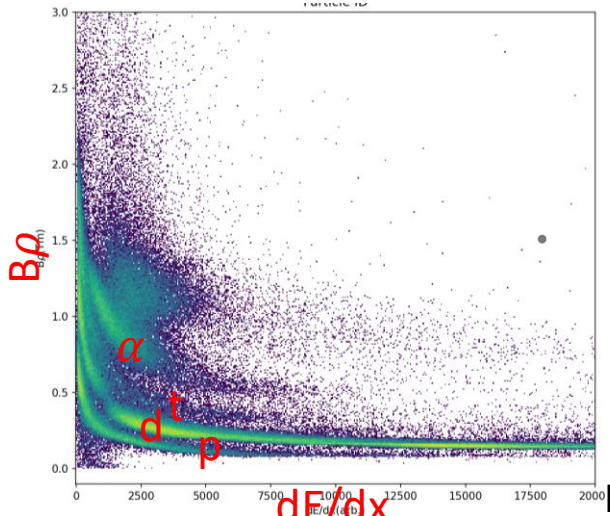


3D tracks

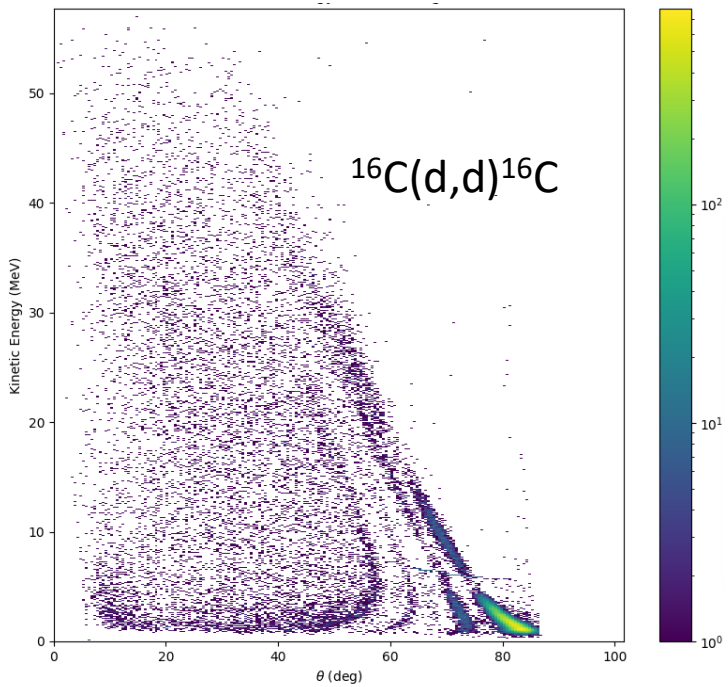


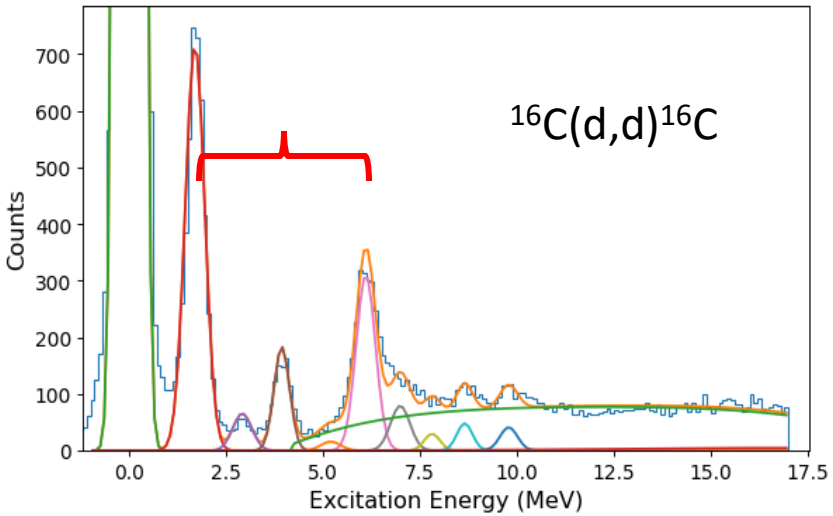
Fitting of Bρ



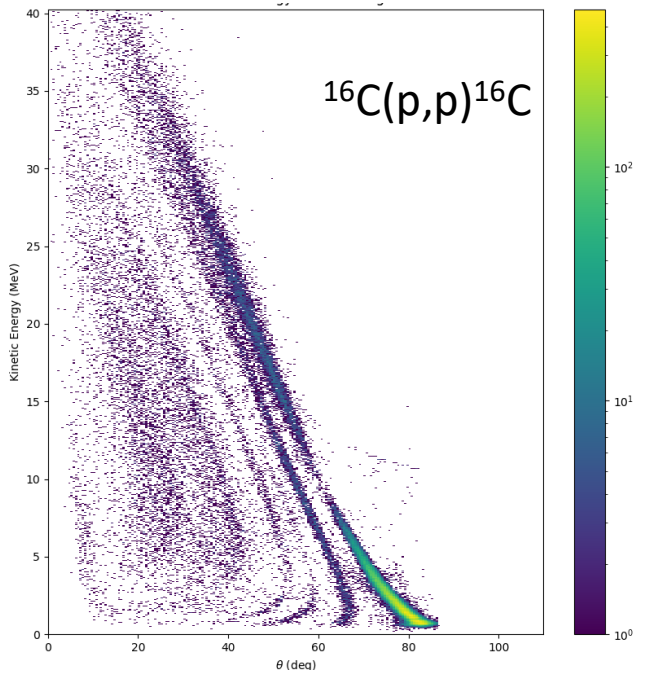


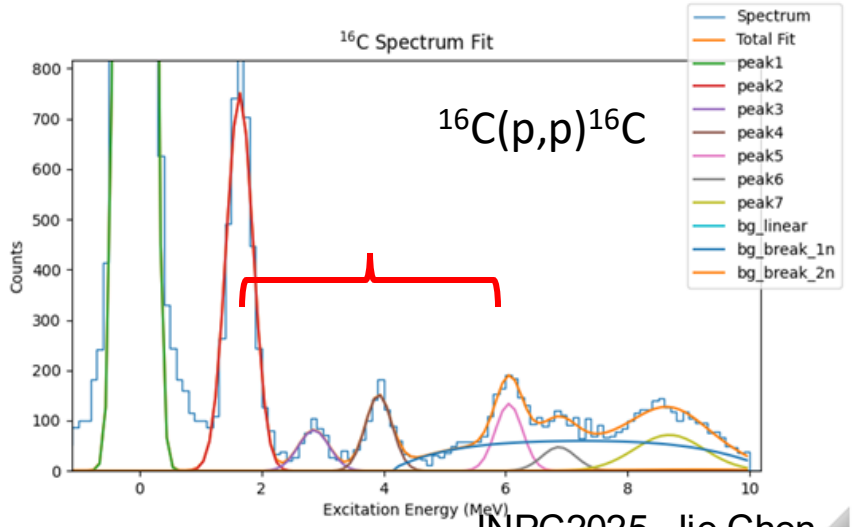
Proton and deuteron inelastic scattering on ^{16}C





- Energy resolution ~ 500 keV
- Simultaneous measurement of (*d,p*) (*d,t*) and (*d,d'*) reactions with **~100 pps** beam within one week!
- Open wide opportunities in the future with weak exotic beams





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